

LOW PROFILE INTEGRATED MODULE INTERCONNECTS
AND METHOD OF FABRICATION

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Field of the Invention

This invention relates to apparatus and method for interconnecting integrated modules.

More particularly, the present invention relates to
10 apparatus and method for interconnecting integrated
modules with low profile interconnects having improved
reliability.

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Background of the Invention

At the present time, many electronic circuits are integrated into small components or modules that are then mounted on larger carriers, such as printed circuit boards
20 and the like. One of the major problems that arises in this process is the differences in thermal expansion between the material making up the integrated modules and the material making up the carriers. For example, a commonly employed material for integrated modules is
25 ceramic. Ceramic integrated modules are generally mounted on some type of printed circuit board employing a hard plastic. The difference in thermal expansion in these materials produces a thermal expansion mismatch that can

seriously effect the interconnect reliability and/or the life of the product.

Generally, the integrated modules have electrical traces distributed around the lower surface. In the prior art, the electrical traces of the integrated modules are electrically and physically connected to mounting and connecting pads on a printed circuit board by means of solder balls. The center of the module's lower surface can be considered as a zero stress or neutral point with connections spaced from the center having more stress, and the farther connections are spaced from the center the more stress they realize. Some of this stress is relieved by the solder balls, which provide a small amount of resiliency or movement. To further relieve this stress, the height of the solder ball is increased. The standoff height and the distance of the solder joint from the thermal expansion neutral point are well known to be the most critical factors responsible for solder joint thermal fatigue. Higher standoff heights and smaller distances from the thermal expansion neutral point are preferable.

Present demands for lower profile structures and larger integrated modules pose serious reliability issues. Generally, a customer specifies a maximum height (the distance between the surface of the mounting board and the upper surface of the module) that can be tolerated. The manufacturer must then arrange a compromise between the standoff height and the amount and position of the components in the module. Clearly, as the standoff height

is increased to improve the interconnect thermal fatigue life, the number of components in the module must be reduced to achieve the specified maximum height.

Accordingly it would be highly desirable to provide
5 apparatus and a method of reducing the standoff height and improving solder joint thermal fatigue life without reducing the reliability.

10 Brief Description of the Drawings

Referring to the drawings:

FIG. 1 is a simplified side view of a prior art module, illustrating the mounting structure;

15 ~~FIG. 2 is a simplified view in bottom plan of a prior art module, illustrating thermal expansion distances from the thermal expansion neutral point;~~

FIG. 3 is an enlarged sectional view of a portion of an assembly including a plurality of modules in accordance
20 with the present invention;

FIG. 4 is a greatly enlarged, detailed view of a portion of a single layer of the assembly of FIG. 3;

FIG. 5 is a simplified side view of a single module after being cut from adjacent modules in the assembly of
25 FIG. 3;

FIG. 6 is a simplified view in bottom plan of the module of FIG. 5;

FIG. 7 is a view in bottom plan, similar to FIG. 6, of a module including a stress relief anchor pad;

FIG. 8 is an enlarged sectional view of a single solder connection to a module in accordance with the present invention, taken along line 8-8 of FIG. 7;

FIG. 9 is a top view of a portion of the module in accordance with FIG. 8;

FIG. 10 is an enlarged sectional view of another single solder connection to a module in accordance with the present invention; and

FIG. 11 is a top view of a portion of the module in accordance with FIG. 10.

Description of the Preferred Embodiments

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Turning now to FIG. 1, a simplified side view of a prior art module 10 is illustrated. Module 10 includes a plurality of terminals 11 formed on the lower surface thereof. As is well known in the art, terminals 11 are connected internally to the circuits and components integrated within module 10. Terminals 11 also serve to mount module 10 on a supporting substrate 12. Supporting substrate 12 has a plurality of mounting/connecting pads 14 formed on the upper or mounting surface 15 and positioned to coincide with terminals 11 of module 10. Solder balls 16 are positioned between terminals 11 and mounting/connecting pads 14. During assembly, solder balls 16 are partially melted so as to physically and

electrically adhere to terminals 11 and mounting/connecting pads 14. Thus, solder balls 16 physically mount module 10 on supporting substrate 12 and electrically connect terminals 11 to mounting/connecting pads 14.

Referring additionally to FIG. 2, a central point, designated 17, of the lower surface of module 10 is considered as a zero stress or neutral point with terminals 11 spaced from point 17 having increasing amounts of stress. The farther terminals 11 are spaced from point 17 the more stress they realize. In the example illustrated in FIG. 2, a terminal 11 situated in the corner of module 10 is spaced the farthest from point 17 and experiences the most stress, indicated by an arrow 18. Some of this stress is relieved by solder balls 16 (see FIG. 1), which provide a small amount of resiliency or movement. To improve the stress relieving characteristics of solder balls 16, the standoff height (designated h_s in FIG. 1) between the lower surface of module 10 and upper surface 15 of supporting substrate 12 is increased. The standoff height h_s and the distance of the solder joint from thermal expansion neutral point 17 are well known to be the most critical factors responsible for SMT solder joint thermal fatigue.

Present demands from customers include fabricating products with lower profiles, designated h in FIG. 1. Also, integrated modules are becoming larger. Both the lower profiles and the larger modules pose serious

reliability issues since they directly conflict with higher standoff heights and shorter distances from neutral point 17. When a customer specifies a maximum height h that can be tolerated, the manufacturer must compromise
5 between standoff height h_s and the amount and position of the components in the module. Clearly, as standoff height h_s is increased to improve the solder joint thermal fatigue life, the number of components that can be included in module 10 must be reduced to achieve the
10 specified maximum height h .

Turning now to FIG. 3, an enlarged sectional view is illustrated of a portion of an assembly or stack 20 including a plurality of modules 21, 22, and 23. Assembly 20 is illustrated to aid in describing a method of
15 fabricating a low profile integrated module, in accordance with the present invention. Here it should be specifically understood that assembly 20 could include a wide variety of sheets of materials, such as ceramic materials, high density interconnect printed circuit
20 boards (HDI/PCB), presently known as FR4, and substantially any material wherein electrical circuits and components are included in sheets and stacked to form a complete circuit or electrical component.

In this preferred embodiment, a plurality of sheets
25 of unfired or green ceramic material are provided for exemplary purposes. A typical example of one sheet 25 is illustrated in FIG. 4. Each sheet 25 includes a plurality of module components 26 defined by sides 27 and formed

adjacent each other so as to share sides 27. Each component 26 includes some electrical traces (designated 28 in FIG. 4), and may further include some electrical components such as capacitors, inductors, resistors, semiconductor integrated circuits (such as an IC designated 29), etc. Each component 26 also includes vias extending therethrough, some of which (designated 30) are located intermediately between sides 27 and some of which (designated 32) are formed in an elongated configuration to extend across sides 27 into adjacent components 26.

In a preferred embodiment, vias 30 are formed, using punches, drills, lasers, etc. (hereinafter referred to as "punching"). Vias 32 are formed by punching a plurality of adjacent, partially overlapping, substantially round holes (referred to hereinafter as nibbling) to define a single via with an elongated cross-section. It will of course be understood that various sizes and shapes of vias can be formed, including but not limited to square, rectangular, round, oblong, etc., using, for example, nibbling and the round and elongated vias shown in FIGS. 4 and 6 are illustrated only to simplify an understanding of the fabrication process. As an example of the size of the various vias, the cross-sectional dimension of the exposed face of via 32, designated 33 in FIG. 6, is in a range of 125 μm to 500 μm .

As stated above, sheets 25 are formed of unfired or green ceramic material which, as is known in the art, usually includes Al_2O_3 particles, glass particles, and a

binder, generally including organic material. After all of the vias 30 and 32 are properly formed in sheet 25, a metal paste, in this preferred embodiment an 80% silver and a solvent, is forced into the vias as, for example, by using a squeegee or the like. The solvent in the silver paste has a tendency to creep into the unfired ceramic material sides of the vias and firmly bind the silver paste in the vias. Here it will be understood that the metal paste can include any electrically conductive metal with a melting point generally greater than the firing temperature of the green ceramic sheets, i.e., generally greater than 800°C. It will further be understood that normal solders and the like can be used, if desired, in sheets of material which do not require high temperature curing or firing, such as the FR4 mentioned above.

Turning again to FIG. 3, it can be seen that a plurality of sheets 25 (in this example three) are stacked or positioned in overlying relationship with sides 27 and vias 32 vertically aligned to form common vias 32 and common sides 27 through the entire stack. It will of course be understood that internal vias 30 and various other connections are also aligned to provide one or more complete interconnected circuits.

Another plurality of sheets 35, formed of unfired or green ceramic material similar to sheets 25, are fabricated to include module components similar to module components 26 of sheets 25. Generally, the fabrication process for sheets 35 is similar to that described above

for sheets 25, except that vias 32 are not included. Sheets 35 include some electrical traces, and may also include some electrical components such as capacitors, inductors, resistors, semiconductor integrated circuits, etc. Further, Sheets 35 include intermediate vias, similar to vias 30 in sheets 25, to provide interconnects between the various sheets 35 and 25. The plurality of sheets 35 (in this example three) are stacked or positioned in overlying relationship with the sides and any vias and components aligned to form one or more complete interconnected circuits.

As can be seen from FIG. 3, sheets 25 are stacked in overlying relationship over sheets 35 with sides 27 aligned so as to form a plurality of vertically aligned modules 21, 22, and 23. Modules 21, 22, and 23 are positioned in adjacent abutting relationship so as to share common sides 27 with the next adjacent module on each side. As is understood by those skilled in the art, sheets 25 and 35 are very thin and, generally, the total number of sheets used depends upon the circuit or circuits being integrated as well as any limitations on the height h specified by a user of the module (e.g., 2 mm).

Further, the number of sheets 25 and the number of sheets 35 incorporated, depends upon a desired vertical length for the common vias 32. Practically, the number of sheets included in stack 20 could vary from a minimum of one sheet 25 and one sheet 35 to as many as twenty total sheets, or more. In this preferred embodiment, the number

of sheets 25 and the number of sheets 35 in stack 20 is determined so that the common vias 32 extend vertically in a range from approximately 25 μm to approximately one half of the height of the stack (i.e., a distance between a lower surface of a lower sheet and an upper surface of an upper sheet).

It should be understood that, while a specific procedure for assembling stack 20 of sheets 25 and sheets 35 has been described in a way that enhances the understanding, any convenient assembly procedure may be followed. For example, it is generally expedient to form all of the required sheets 25 and 35 in advance and then stack them in the aligned position in one step. The exact sequence of steps described above and hereafter in achieving the stack of sheets is not critical to the invention and may be varied according to specific embodiments being fabricated.

Once stack 20 of unfired or green ceramic sheets has been assembled as illustrated in FIG. 3, the stack is cut or otherwise divided into individual modules. In this preferred embodiment stack 20 is cut with a very sharp instrument. The cutting is easily accomplished since sheets 25 and 35 are still formed of unfired or green ceramic. Stack 20 could be divided into individual modules after firing but fired ceramic is very hard and the process would be substantially more difficult. In FIG. 3, the sides 27 of adjacent modules 21 and 23 and adjacent modules 21 and 22 are indicated with broken

lines. Here it should be noted that sides 27 extend through vias 32 so that upon cutting stack 20 along the broken lines each module 21, 22, and 23 has portions of vias 32 extending along the sides thereof, as illustrated in FIG. 6. Also, the cutting process is performed with sheets 25 at the top of the stack and sheets 35 at the bottom of the stack so that silver paste in vias 32 is held in place by the solid surface of sheets 35 during the cutting operation.

Once stack 20 is separated into individual modules (e.g. modules 21, 22, and 23), the modules are fired to cure the ceramic. As is understood in the art, the firing temperature is generally dictated by the composition of the green ceramic material. In this preferred embodiment, the green ceramic material includes Al_2O_3 particles, glass particles and an organic binder. In this case, the glass particles dictate the firing temperature, since the glass particles melt sufficiently to bind the aluminum particles together at a temperature of approximately 875° C. Also, at this temperature the organic binder is driven off to leave a ceramic comprising Al_2O_3 particles bound together by at the least partially melted and reformed glass. Also, the various sheets 25 and 35 are bound into a virtually single structure by the firing process. In the firing process the individual modules contract or shrink approximately 13%, but the shrinkage is substantially uniform so that it does not affect the final module.

Further, during the firing process the silver paste in vias 30 and 32 is hardened firmly into position.

Turning now to FIG. 7, a bottom view of another final module 21 is illustrated. A plurality of vias 32 are distributed along each side 27 and a stress relief anchor pad is positioned on the bottom surface. In this specific embodiment, the stress relief pad includes a centrally located octagonal element 36 and a round element 37 positioned in each corner. The stress relief pad is formed on the lower surface of the final sheet 25 (e.g., the top sheet in FIG. 3) and includes metal that is ultimately soldered to a supporting substrate (as will be described presently).

As explained briefly above, a central point of the lower surface of a module is considered as a zero stress or neutral point and the farther terminals are spaced from the neutral point the more stress they realize. In the embodiment illustrated in FIG. 7, the stress relief pad reduces stresses at adjacent interconnects or vias 32. Octagonal element 36 and round elements 37 are designed and positioned so that each via 32 is spaced approximately an equal and short distance therefrom. It will be understood that octagonal element 36 and round elements 37 could be formed as a single integrated stress relief pad if desired or they could be divided into additional elements, with the purpose being to provide equal and short distances between each via and the stress relief pad.

The individual fired modules (e.g., module 21) can then be mounted on a supporting substrate 40, as illustrated in FIG. 8. In this preferred embodiment, supporting substrate 40 is a printed circuit board or the like with a mounting surface 42. Mounting pads 43 are fabricated on surface 42 using any well known process and a layer of reflowable solder or solder paste is applied using any well known technique, such as printing or the like. While only one mounting pad 43 is illustrated in FIG. 8, for convenience, it will be understood that any or all of vias 32, any vias 30, and/or any stress relief pad or pads, which it is desired to connect to supporting substrate 40, will generally have an aligned mounting pad 43 associated therewith.

Referring additionally to FIG. 9, it can be seen that mounting pads 43 are formed with a surface area that is larger than the lower or adjoining surface area of the associated via 32. As an example, if via 32 is formed with a rectangular cross-sectional area having a maximum side dimension of approximately 125 μm , the surface area of mounting pad 43 may be generally rectangular with a length to width ratio of about 2:1. Solder (e.g., solder paste, etc.) is prepositioned on mounting pad 43, by solder printing or the like, to achieve a desired amount. The structure is then heated in a well known fashion to melt or reflow the solder paste or solder positioned on mounting pad 43. The prepositioned solder wicks-up the outside of via 32 to form a fillet 45, as illustrated in

FIG. 8. The amount of prepositioned solder is selected so that the final standoff height h_s is preferably in a range of from 75 μm to 125 μm . This range allows the solder associated with the module to be printed at the same time as solder for other board elements or modules and the entire board 40 can be printed in one step.

Referring again to FIGS. 8 and 9, a connection and/or mounting pad 46 is provided on the lower surface of the lower sheet 25 of module 21 in contact with the lower surface of each via 32. Pad 46 has a surface area larger than the cross-sectional area of via 32 (see FIG. 8) so as to spread the stress over a larger area. The surface area of mounting pad 43 on supporting substrate 40 is then formed with a generally rectangular shape having a length to width ratio of about 2:1 and a surface area at least twice as large as the surface area of pad 46 (see FIG. 9).

Turning to FIGS. 10 and 11, another embodiment of apparatus for reducing stress is illustrated. In this embodiment, components similar to those illustrated in FIGS. 8 and 9 are designated with similar numbers and a prime is added to each number to indicate the different embodiment. In this embodiment, a connection and/or mounting pad 46' is provided on the lower surface of an interior sheet next to the lower sheet, with one or more lower sheets 25' having cutouts aligned with pad 46'. While only one mounting pad 43' is illustrated in FIGS. 10 and 11, for convenience, it will be understood that any or all of vias 32', any vias 30', and/or any stress relief

pad or pads, which it is desired to connect to supporting substrate 40', will generally have an aligned mounting pad 43' associated therewith. In this embodiment, pad 46' is recessed into the lower surface of module 21' so that the total height of the solder, designated h_{s01} in FIG. 10, is greater and, therefore, further reduces the stress on the joint. Depending upon the specific application and the number of vias required, pad 46' can be recessed one to several sheets of module 21' to increase the height h_{s01} .

It should also be noted that by recessing pad 46', the standoff height h_s ' of module 21' can be reduced to $25\mu\text{m}$ or less if it is desired.

One additional problem that arises is the tendency of the silver to be scavenged or alloyed with any Sn based solder during the reflow (high temperature) process. Because of this scavenging or alloying, the integrity of solder interconnects becomes brittle and weakened. The effects of the scavenging or alloying of the silver can be overcome by providing a larger quantity of silver. For example, pad 46' can be formed of silver in a fashion similar to that described for the filling of the vias. In some specific applications, the cutout or cutouts in the lower sheet or sheets 25' of module 21' can be filled with silver in a fashion similar to that described for the filling of the vias. This cutout enables a thickness increase from 47 to 47' which will provide the additional silver to ensure strong interconnections.

Thus, vias 32 positioned in sides 27 of module 21 are constructed to extend only partially up the sides so as to improve the fabrication process. By extending vias 32 only partially up sides 27, the internal circuitry can be easily connected through internal electrical traces 28 and vias 30. The assembled or stacked unfired ceramic sheets of integrated circuitry are separated or cut while in the green state to greatly simplify the separation process. Further, by extending vias 32 only partially up sides 27, sheets 35 form a base for the silver or conductive metal in vias 32 so that they can be easily bisected without driving the silver or conductive metal out.

The fired and otherwise completed integrated modules are mounted on a supporting substrate with a greatly reduced standoff height h_s' (e.g., 75 μm to 125 μm versus a 375 μm ball in the prior art). Because of the conductive metal filled vias positioned along the edge and the size of the mounting pads on the supporting substrate, the solder used in the mounting and connecting process wicks-up the side of the module to form a fillet, which greatly strengthens the connection/mount and substantially increases reliability and life of the solder joint.

While we have shown and described specific embodiments of the present invention, further modifications and improvements will occur to those skilled in the art. We desire it to be understood, therefore, that this invention is not limited to the particular forms shown and we intend in the appended claims to cover all

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